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Do Sunspots Matter for Cycles in Agricultural Lending: a VEC Approach to Russian Wheat Market

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Abstract

In this article, we test a hypothesis about the influence of sunspot cycles on cycles of agricultural lending on example of wheat market. Analyzing data on Russian wheat market for period from 1990 to 2015 we test a hypothesis of solar activity's impact on cycles in agricultural lending in the short and long run. Using a vector error correction approach to the sample, we obtain the following results: in the long run, sunspots, wheat yield, world wheat prices, and non-performing loans (NPL) for wheat market are related. In the short run, level of non-performing wheat loans depends only on wheat yields. However, results of Granger causality test confirm that wheat yield dynamics and sunspots Granger cause non-performing bank loans in Russia, which confirms our hypothesis of solar activity importance for agricultural lending activity.

Keywords

Solar activity, wheat market, agricultural lending, crop yield, vector error correction, Granger causality test, credit cycle.

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Introduction

World agricultural market: current challenges

Contemporary global economic system is characterized by high turbulence and increased amplitude of cyclic fluctuations in many markets for goods and services. The formation of a new era of economic instability has led to necessity of revision of many, seemingly immutable, pillars of economic science. Empirical deviations from classical elegant models has brought the business community and public authorities in different countries to increase their emphasis in ensuring stability of economic development. No exception present market theories for goods and services and, in particular, agro-industrial sector. In the context of acute problem of food security in many countries of the world, in the context of declining budget surplus and the need for rationing funds to support a variety of industries due to increasing tensions in global economic infrastructure, in context of increased probability of tail risks (black swans) occurrence increasing, there is a strong need to modify risk management and methods of their estimation, not to mention forecasting tools.

In case of the agricultural sector, one of the main directions of development of scientific thought as a reaction to increased uncertainty, is a rising interest in strengthening the predictive and forecasting power of models that evaluate the potential damage and benefits from changes in cosmic and terrestrial climate patterns in order to determine the impact on the agricultural sector, particularly on crops yield, exploring areas of risk farming, influence of regional and seasonal deviations of climatic and physical sense (for example, geomagnetic fields) on the stability of yield of different crops. A thorough theoretical review of methods and models of crop yield forecasting is presented in paper by Basso et al. (2013)

Thus, it can be assumed that forecasting and risk assessment in the agricultural sector becomes one of main directions in conventional economic science.

It seems logical to assume that assessment of potential risks and forecasting deviations of agricultural sector has an applied character. Firstly, an ability to predict changes in exposure to physical and climatic factors of crop yields may contribute to optimization of public financial support to agricultural sectors on the one hand. In case of expected high crop – additional support.

In case of expected low yield – redistribution of financial resources to other sectors, or partial supporting for providing food security. In case of financial markets of developing countries, agricultural sector and its lending is seen by many banks as the most marginally profitable, and in some cases unprofitable directions. (Salin et al., 2007; Sadanandan, 2014) However, importance of agriculture leads to implementing tools in form of interest rate subsidies as well as restructuring of current debt burden. For example, in case of Russia, the share of non-performing bank loans (NPL) to agricultural sector accounts for over 20% of the total outstanding debt. For wheat market, the figure varies between 1990 and 2015 from 4.6% to 39.4%. Such deviations in dynamics of bad debts are a consequence of the credit risk realization, even given standard support of agricultural sector. (Bank of Russia Statistical Bulletin, 1990-2015).

The specifics of credit risk in agriculture usually refers to exogenous factors (temperature, deviation from average values of rainfall, climatic shocks, etc.), so in most cases, the process of assessing credit risk when issuing loans is conditional and heavily sponsored by government or lending to agricultural sector being concentrated in state "controlled" banks, which leads to growing financial losses and a rising need for continued support.

However, strengthening of risk management process by private banks and bodies of state financial support should be based on a solid evidence base. In particular, lenders must have confidence in tools and techniques to assess risks on the one hand, on the other – to have evidence of significance of factors included in models. Otherwise, borrowers may face credit rationing in form of underlending of agricultural sector.

In the Russian scientific field there are only a few studies (discussed below) on the impact of climate change on individual agricultural zones and regions. Moreover, no studies, arguing for inclusion of climatic and physical factors in bank models for assessing risks of agricultural lending aimed to ensure financial stability during cycles of agricultural lending is present.

In other words, the main objective of this paper is to empirically test a hypothesis, stating that there exists a causal relationship between solar cycles and cycles in agricultural lending on example of Russian wheat market, thereby stressing importance of accounting climatic factors when forecasting yield and evaluating associated credit risk.

In this regard, we refer to an overview of main studies on the issue of relationship between natural factors, dynamics of economic variables, and in particular, crop yields.

Literature review

The question of relationship between solar activity, climate change and dynamics of economic variables has attracted attention of researchers many centuries ago, yet still being actual.

The first theories of economic cycles were associated with exogenous events or exogenous shocks. For example, one of the now-canonized works in this field is the study of Herschel (1801), which revealed the presence of a correlation between sunspots, as a manifestation of solar activity and wheat prices for the period from 1779 to 1818. He identified a 22-year cycle of solar activity, which based his hypothesis: solar activity significantly influenced the price of wheat.

The next step in developing Herschel's hypothesis was sunspot cycles hypothesis of W. S. Jevons (1879), which identified 11-year solar cycles and based on Herschel's hypothesis allocated a transmission mechanism of solar activity. The omission by Herschel of 11-year cycles is because the observations came during the Dalton Minimum – a period of low solar activity. In case of Jevons' observations, the essence of the hypothesis was reduced to transmission of sunspots effect: the initial shock in low (high) solar activity leads to a decrease (growth) of crop yields and a decline (increase) of yield (secondary shock) leads to reduction (expansion) of business activity in the economy. Around the same time, a colleague of Jevons – John Mills (1875) puts forward the first theory of the Credit cycle, also stemming from Jevons hypothesis. Unlike Jevons, Mills at the heart of economic fluctuations has placed not so much a change in the rate of return on the markets, but rather expectations of its changes, creating one of the first behavioral theories of business cycles.

Before continuing to review the evolution of this approach up to the present day (conventionally it can be called Herschel-Jevons approach), it is necessary to note one important fact. We in any case, like all researchers studying the impact of natural processes on economic activity, do not claim that dynamics of natural phenomena and them only are sufficient and enough to explain changes in economic processes. At the same time, denying presence and importance of certain natural processes in economic dynamics seems to us inappropriate in connection with the presence of significant argumentation base.

The development of Herschel-Jevons approach in the twentieth century was varying. In other words, stemming from simple relationship between solar activity and economic process, several main directions of development exist to this day.

The first area of research is maintaining a classic narrow nature of the hypotheses of Herschel and Jevons, and is mainly aimed at finding the relationship (transmission) between solar activity, climate change and the functioning of agriculture, environment across countries and regions. In this area there are two blocks.

The first block of studies is devoted to the direct transmission of solar activity in the form of sunspots, solar radiation on crop yields. Most of research in this area is based on the study of influence of amplitude and duration of solar activity on vegetation processes of plants and crops. One of the brilliant research conducted by Harrison (1976) showed that there is significant positive correlation between solar activity and the yield of different crops in the United States. To similar conclusions come researchers who conducted similar studies in Canada, UK, India, Europe and Africa for various time periods, sometimes exceeding hundreds of years (a short description of the results is presented in Table 1). One of the important research studies that adds to significance of this hypothesis is a paper of Pustil'nik and Yom Din (2004, 2013), which is based on the analysis of agricultural markets in countries of Europe and their relationship with cycles of solar activity, between which there also was discovered a significant connection.

The second line of studies is devoted to the question of indirect solar activity's influence on the yield of agricultural crops. The basis of the transmission includes effects of solar activity on the Earth's geomagnetic field, climate changes, degree of cloudiness, deviations in rainfall, which also has a significant potential impact on crop yields. One of the most significant works in this area is the study by Marsh and Svensmark (2000), which, being based on the analysis of worldwide data, presents a map of dependence of level of cloud cover the earth and temperature from solar radiation (cosmic rays). The detection of the correlation was an important step for the development of scientific research in the field of the relationship between solar activity and climate. For example, Hiremath (2006) proved the existence of a connection between solar cycles and deviations in rainfall. To similar conclusions about dependence of the global temperature changes from solar radiation comes and Gupta (2015).

It is important to note that at the global level in some cases and countries, the dependence is statistically insignificant as in case of relationship between solar radiation and crop yields, so in case of dependence of cloud cover from cosmic ray radiation. This fact is reflected in several papers (e.g. Dewey (1968), Marsh and Svensmark (2000), Lockwood (2012), Love (2013), Pustil'nik and Yom Din (2013), Savin and Leo (2016)). The explanation for this peculiarity is due to physical processes. So, for example, Pustil'nik and Yom Din (2013) studying dependence of agricultural crops' yield from changes in solar activity, recommend to take into account sensitivity of local weather (cloud cover, atmospheric circulation) and atmospheric and climate anomalies in the areas of agriculture. However, most of papers confirm the presence of indirect impact of solar activity on crop yields.

The second direction (mainly in behavioral and experimental economics) in contrast to the first, aims to explore direct and indirect linkages between solar cycles and their derivatives (climate change, weather conditions, magnetic fields) on behavior of economic agents and macroeconomic variables. Because for us this direction is not of a substantial nature, we confine ourselves to a brief review of main papers in this field.

As can be seen from a summary presented in Table 1, many authors come to conclusion that there is a statistically significant and positive relationship between solar activity and dynamics of social and macroeconomic variables – employment, mortality rates, output rates, trading, etc. However, it is important to note that the influence of natural factors should be regarded as the accelerator – a factor, influencing economic activity, rather than the source.

Concluding, it can be noted that provided review of research on relationship between solar activity (sunspot cycles) and economic processes, allows to assume that between them there is a certain relationship on the one hand. On the other hand, we assume that sunspots have the potential to impact (both direct and indirect) the yield of agricultural crops. The latter, in turn, should influence cycles of agricultural lending (in our sample - the wheat market).

Unfortunately, in contemporary literature a question

Author	**Sample**	**Method**	**Sunspots-Socio-Economic Fluctuations**
Walsh (1993)	Earth's geomagnetic field-business cycles (1870-1960)/USA	Time series, correlation analysis	Significant, positive, partial correlation
Saunders (1993)	Stock Prices Fluctuations-Local Weather (New York)	Correlation, regression analysis	Significant, positive
Hirshleifer and Shumway (2003)	Sunshine index – Stock returns/ USA	Correlation, regression analysis	Significant, positive. Rain(snow) falls – insignificant. Support for solar activity hypothesis
Kamstra et al. (2003)	Stock returns-Amount of daylight/Worldwide	Regression analysis (VAR model)	Seasonal affective disorder (winter depression) effect confirmed. Support for solar effect on sentiment
Otsu et al. (2006)	Sunspots-Unemployment/ Mortality (1971-2001)/Japan	Correlation, regression analysis	Significant, positive for males, negative for females
Gorbanev (2012)	Sunspot Cycles-Recessions/ Unemployment (Worldwide)	Time series, correlation analysis	Significant, positive
Novvy-Marx (2014)	Solar, Climate Fluctuations – Market Anomalies/USA	Regression analysis (Panel VAR model)	Significant, positive

Author	**Sample**	**Method**	**Solar Activity/Climate Change-Crop Yield**
Herschel (1801)	Sunspot-Wheat Price/England	Time series analysis	Positive
Jevons (1879)	Sunspots-Crop Prices (Corn)/ England	Time series analysis	Positive
Dewey (1968)	Double sunspot cycle (22y) – Cycles in financial, manufacturing, agricultural sectors/USA	Time series, correlation analysis	Ambiguous, partial correlation revealed
Monteith (1972)	Solar radiation -crop vegetation/ Kenya, Congo, Nigeria	Predictive regression model	Significant, positive
Harrison (1976)	Sunspot Cycles/Crop Yields/USA (1866-1873)	Regression analysis	Significant, positive: high sunspot numbers lead to high crop yield
Marsh and Svensmark (2000)	Solar activity (cosmic rays) – Global cloud cover/Worldwide	Correlation analysis	Significant correlation: high solar activity leading to low cloud cover and high top temperature in low clouds, vice versa
Pustil'nik and Yom Din (2004)	Wheat Prices-Solar Cycles/ Medieval England (1249-1703)	Correlation, regression analysis	Significant, positive
Hiremath and Mandi (2004)	Solar Activity-Indian Monsoon Rainfall Occurrence (1871-2000)	Correlation analysis	Significant positive correlation
Garnett et al. (2006)	Sunspot Activity-Crop Yield/ Canada (1950-2004)	Correlation analysis	Significant, positive: high sunspot numbers leading to low summerfall, fall in crops yield
Hiremath (2006)	Solar Activity-Rainfall Occurrence (1871-2000)/India	Correlation analysis	Significant, positive: high(low) sunspot numbers lead to low (high) rainfall occurrence
Lockwood (2012)	Solar activity-Climate change (temperature)/Eurasia	Regression analysis	Significant, positive in case of seasonal analysis
Pustil'nik and Yom Din (2013)	Solar Activity-Prices for agricultural commodities/ European agricultural markets (1650-1715)	Correlation, regression analysis	Depends on sensitivity of local weather; sensitivity of crops to weather anomalies; degree of market's isolation
Love (2013)	Sunspots-Wheat Prices (1868-2012)	Regression analysis	Statistically insignificant. Sunspot numbers fail to predict future wheat prices in retrospective

Source: author's compilation

Table 1: Summary of relevant literature.

Author	Sample	Method	Solar Activity/Climate Change-Crop Yield
Huhtamaa et al. (2015)	Temperature fluctuations-Crop yield (rye, barley)/Finland (1861-1913)	Correlation, regression analysis	Significant, positive
Gupta et al. (2015)	Sunspot Numbers-Global temperature (1880-2013)	Granger causality test, frequency domain test	Sunspots cause global temperature fluctuations (frequency domain test)
Savin and Leo (2016)	Wheat Yield-Solar caused fluctuations in Earth's magnetic field /Worldwide	Correlation analysis	Significant, positive and negative for sample, depends on meteorological conditions

Source: author's compilation

Table 1: Summary of relevant literature (continuation).

of relation between solar activity and cycles of agricultural lending as a manifestation of economic fluctuations has not been studied thoroughly. Thus, our study, devoted to search for causality between cycles in agricultural lending and solar cycles, is designed to provide scientific argumentation base for developing and strengthening methods of credit risk assessment and allocation of public funding in an optimizing manner.

The scientific novelty of this study then is to find a relationship between dynamics of NPL for wheat production in Russia and sunspot cycles in the short and long run.

Materials and methods

Research methods

To test the hypothesis about relationship between sunspots, wheat yield, world wheat prices and cycles in agricultural lending, we use econometric techniques to analyze time series. The algorithm of the ongoing study is determined by several key stages. First and foremost, one should test sampled variables on stationarity or order of cointegration, since the time series must have the same order, as can be seen from equation (1). Secondly, it is necessary to determine presence/absence of correlation in long term between the variables in the equation. To check this assumption we use a Johansen cointegration test. If condition of stationarity of sampled time series in the first order I(1) is met, it is possible to use VEC model. In case of confirmation of presence of cointegration between the variables of the sample, residuals of the equilibrium regression can be used to estimate error correction model. Also based on VEC model it is possible to identify short-term causality between sampled variables. For this purpose, we use the Wald test. To determine predictive power of variables we use Granger Causality Test – for testing predictive causality of explanatory variables. The final stage of constructing a model is to conduct diagnostic tests to determine validity of the model. These include testing for heteroscedasticity, serial correlation, normality and stability of the model.

Unit Root Test

For the analysis of long-term relationships between the variables, Johansen and Juselieus (1990) admit that this form of testing is only possible after fulfilling the requirements of stationarity of the time series. In other words, if two series are co-integrated in order d (i.e. I (d)) then each series has to be differenced d times to restore stationarity. For d=0, each series would be stationary in levels, while for d=1, first differencing is needed to obtain stationarity. A stochastic process (a collection of random variables ordered in time) is said to be stationary if its mean and variance are constant over time, i.e. time invariant (along with its autocovariance). By contrast, a nonstationary time series have a time-varying mean or a time-varying variance or both. It is important to cover non-stationary variables into stationary process. Otherwise, they do not drift toward a long-term equilibrium. There are two approaches to test the stationarity: Augmented Dickey and Fuller (ADF) test (1979) and the Phillips-Perron (P-P) test (1988). Here, test is referred to as unit-root tests as they test for the presence of unit roots in the series. The use of these tests allows to eliminate serial correlation between the variables by adding the lagged changes in the residuals of regression. The equation for ADF test is presented below:

$$\Delta Y_t = \beta_1 + \beta_2 t + aY_{t-1} + \delta_3 \sum \Delta Y_{t-1} + \varepsilon_t \qquad (1)$$

where ε_t is an error term, β_1 is a drift term and $\beta_2 t$ is the time trend and Δ is the differencing operator. In ADF test, it tests whether a = 0, therefore the null and alternative hypothesis of unit root tests can be written as follows:

H0: a = 0 (Yt is non-stationary or there is a unit root).

H1: a < 0 (Yt is stationary or there is no unit root).

The null hypothesis can be rejected if the calculated t value (ADF statistics) lies to the left of the relevant critical value. The alternate hypothesis is that a < 0. This means that the variable to be estimated is stationary. Conversely, we cannot reject the null hypothesis if null hypothesis is that a = 0, and this means that the variables are non-stationary time series and have unit roots in level. However, normally after taking first differences, the variable will be stationary (Johansen and Juselius, 1990). On the other hand, the specification of P-P test is the same as ADF test, except that the P-P test uses nonparametric statistical method to take care of the serial correlation in the error terms without adding lagged differences (Gujarati, 2003). In this research, we use both ADF and P-P test to examine the stationary of the sampled time series.

Johansen co-integration test

To test for presence of cointegration we apply the Johansen test using non-stationary time series (values in levels). If between variables does exist a cointegration, the first-best solution would be using VECM model. An optimal number of lags according to Akaike information criterion for providing Johansen test is determined in VAR space. To conduct Johansen test, we estimate a VAR model of the following type:

$$y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + Bx_t + \epsilon_t \qquad (2)$$

in which each component of y_t is non-reposeful series and it is integrated of order 1. x_t is a fixed exogenous vector, indicating the constant term, trend term and other certain terms. ϵ_t is a disturbance vector of k dimension.

We can rewrite this model as:

$$\Delta y_t = \prod y_{t-1} + \sum_{i=1}^{p-1} V_i \Delta y_{t-1} + Bx_t + \epsilon_t \qquad (3)$$

Where

$$\prod = \sum_{i=1}^{p} A_i - I, \quad V_i = -\sum_{j=i+1}^{p} A_j \qquad (4)$$

if the coefficient matrix $\prod$ has reduced rank r < k, then there exist k x r matrices α and β each with rank r such that $\prod = \alpha\beta'$ and $\beta' y_t$ is I(0). r is the number of cointegrating relations (the cointegrating rank) and each column of β is the cointegrating vector. The elements of α are known as the adjustment parameters in the VEC model. Johansen's method is to estimate $\prod$ matrix from an unrestricted VAR and to test whether we can reject the restrictions implied by the reduced rank of $\prod$ (Johansen, 1991).

Vector error correction model

Granger (1988) suggested the application of Vector Error Correction methodology (VECM) in case if the variables are cointegrated in order to find short-run causal relationships. VECM, therefore, enables to discriminate between long-run equilibrium and short-run dynamics. In this sense, we employ following VECMs to estimate causal linkages among the variables:

$$\Delta ln\, l = a_0 + \sum_{i=1}^{k} a_1 \Delta\, lnl_{t-i} + \sum_{i=1}^{n} a_2 \Delta\, lns_{t-i} + \sum_{i=1}^{m} a_3 \Delta lny_{t-i} + \sum_{i=1}^{o} a_4 \Delta lnw_{t-i} + \lambda ECT_{t-1} + v_1$$

$$\Delta ln\, s = \beta_0 + \sum_{i=1}^{k} \beta_1 \Delta\, lns_{t-i} + \sum_{i=1}^{n} \beta_2 \Delta\, lnl_{t-i} + \sum_{i=1}^{m} \beta_3 \Delta lny_{t-i} + \sum_{i=1}^{o} \beta_4 \Delta lnw_{t-i} + \phi ECT_{t-1} + v_2$$

$$\Delta ln\, y = \eta_0 + \sum_{i=1}^{k} \eta_1 \Delta\, lny_{t-i} + \sum_{i=1}^{n} \eta_2 \Delta\, lnl_{t-i} + \sum_{i=1}^{m} \eta_3 \Delta lns_{t-i} + \sum_{i=1}^{o} \eta_4 \Delta lnw_{t-i} + \chi ECT_{t-1} + v_3$$

$$\Delta lnw = \theta_0 + \sum_{i=1}^{k} \theta_1 \Delta\, lnw_{t-i} + \sum_{i=1}^{n} \theta_2 \Delta\, lnl_{t-i} + \sum_{i=1}^{m} \theta_3 \Delta lns_{t-i} + \sum_{i=1}^{o} \theta_4 \Delta lny_{t-i} + \varphi ECT_{t-1} + v_4$$

where l is non-performing loans for wheat production, s Wolf numbers for solar activity (sunspots), y wheat yield and w world wheat prices (Granger, 1988).

Providing regression analysis of the sampled variables by modeling VECM allows us to determine the existence of substantial and statistically significant dependence not only on the values of other variables in the sample, but also dependence on previous values of the variable.

However, VEC model must meet the requirements of serial correlation‘s absence, homoscedasticity of the residuals and to meet the requirement of stability and normality. Only in this case the results can be considered valid.

Granger causality test

The last stage to determine the relationship and its direction is the use of Granger causality test. So, rejection of the null hypothesis of Granger test (H0), according to which:

$$b_1 = b_2 = ... = b_p = 0, \qquad (5)$$

in favor of the alternative hypothesis (H1) suggests that changes in sunspots or wheat yield or world wheat prices Granger cause changes in NPL share of loans for wheat production. (Granger, 1969)

Materials and data processing

We test a hypothesis of causality between sunspots and cycles of agricultural lending on example of Russian data for the period 1990 to 2015. The base period is one year. Unfortunately, use of quarterly or monthly values of variables for the analysis is hindered due to availability of only annual data on wheat yields and NPL granted for wheat production. Using VECM, we set ourselves a task to determine sensitivity of dynamics of NPL for wheat production to changes in solar activity, wheat yield and dynamics of world prices for wheat.

Data on wheat yield in Russia and NPL is obtained from the statistical database of Federal State Statistics Service of Russia (FSSR) (www.gks.ru) and statistical database of the Bank of Russia (BR) (www.cbr.ru). Data for world prices of wheat is obtained from the statistical database of Food and Agriculture Organization of the United Nations (FAOSTAT). Data for cycles of sunspots – the average values of the Wolf numbers is obtained from the statistical database of the Far Eastern Department for Hydrometeorology and Environmental Monitoring of Russia (FEDHEMR) (www.khabmeteo.ru).

To conduct time-series analysis, all variables were transformed into logarithms. To identify and formally assess the relationship between variables, we use simple correlation analysis. To study sensitivity and causal linkages between the variables in the sample in short-and long-run, we turn to regression analysis, which involves the construction of VEC model of certain type based on stationary time series, testing the model for heteroscedasticity of the residuals, autocorrelation as well as stability and normality. Based on the model, we study predictive causality between variables by applying Granger causality test in VEC domain.

Results and discussion

Table 2 presents the results of correlation analysis between the variables that make up the sample for testing our hypothesis. As can be seen from data presented in this Table, solar activity, expressed through Wolf numbers, has a moderate strength correlation with changes in NPL and wheat yield.

For example, correlation between Wolf numbers and NPL is negative – decline in solar activity leads to an increase of NPL on the background of positive correlation between Wolf numbers and wheat yield (coefficient is 0.54) – an increase in solar activity enhances vegetative processes in crops. The same is true for the relationship between wheat yield and NPL. An increase in productivity leads to a reduction in NPL and vice versa.

This table is notable for two features. First, the correlation analysis does not reflect a significant relationship between Wolf numbers and world wheat prices (the coefficient is only 0.25). The relation is reverse: an increase in solar activity leads to a reduction in world prices due to higher global wheat supply. Second, values of correlation coefficients are far from 1, as well as p-value being more than 5% significance level. This observation is explained quite logically, if we turn to assumptions put forward by Pustil'nik and Yom Din (2013) on effects of Earth's climate and atmospheric

Variable	Non-performing loans	Sunspots (Wolf numbers)	World wheat prices	Wheat yield
Non-performing loans	1			
Sunspots (Wolf numbers)	-0,461511 **[0.0101]**	1		
World wheat prices	0.009509 [0.4820]	-0.25582 [0.1085]	1	
Wheat yield	-0.51731 **[0.0040]**	0.54570 **[0.0023]**	0.43840 **[0.0141]**	1

Note: p-values are presented in brackets; statistically significant p-values – in bold; significance level – 0.05

Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author’s calculation

Table 2: Correlation matrix.

processes to the direct cosmic radiation (solar radiation). Considering these assumptions the lack of a direct linear relationship is quite understandable.

However, the results of correlation analysis cannot be considered exhaustive and reliable due to possible problems of serial correlation, for example. Moreover, since the way of stochastic is different at each time point of the non-stationary series, general stochastic of the series is hard to capture. There is also the probability of obtaining spurious regression.

Building a regression model in our case deals with time series that often exhibit a seasonal pattern (solar activity, crop yields etc.). According to results of Maddala and Kim (1998), in finite samples standard ADF and PP statistics for testing unit root will be biased towards nonrejection of the unit root null if filtered (seasonally adjusted) data are used. In other words, since seasonal adjustment introduces a "non-revertible" moving average (MA) component into time series data, unit root tests will be biased towards non-rejection of the unit root null hypothesis (Maddala & Kim, 1998). Keeping this in mind, we use unadjusted annual values, given that seasonal adjustment could create turning points being randomness in data.

To resolve the problem with the nonstationarity of time series, it is necessary to test for the presence of unit root. The results of ADF and Phillipes-Perron tests are presented in Table 3.

As can be seen from the test results of variables for the presence of unit root in their differentiation to the first order, we can reject the null hypothesis of unit root in each of the variables. Thus, the condition of stationarity at I(1) is performed, which gives us reason to test variables for cointegration. However, it is necessary to determine the optimal time lag. In our case, the Akaike information criterion equals 2 (Table 4).

At first glance, the choice of the time lag value in two years seems inconsistent with empirical observations. However, given the fact that the process of granting a loan and determining its quality is associated with the cycle of production and harvesting of wheat, which requires at least 1 year on the one hand, and on the other, given the non-linear and cumulative nature of relationship between solar activity and its influence on terrestrial processes, it can be assumed that the maximum effect of cumulative amplification (attenuation) of solar activity is achieved in two years in case of our sample. This result is also indirectly supported by results of Marsh and Svensmark (2000), which developed a map of correlations between cosmic rays' penetration of Earth and cloud cover. For Russia's territories (Far East, Volga region, Stavropol Krai), providing most of wheat yield, correlation index is around 0.35 - 0.45, that can be interpreted as low penetration of solar radiation. So, process of radiation accumulation can be counted

	ADF		PP	
	Statistic	Prob.**	Statistic	Prob.**
Levels				
Intercept	10.2460	0.8394	8.7126	0.9422
Intercept and trend	8.1475	0.4164	5.4422	0.4268
First-difference				
Intercept	45.08	0.0000**	43.01	0.0000**
Intercept and trend	31.73	0.0001**	29.52	0.0003**

Note: ** denotes statistical significance at the 5% level of significance
Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author's calculation

Table 3: Results of individual unit root test.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-342.0658	NA	39330063	28.83881	29.03516	28.89090
1	-294.2712	18.35107	12297662	27.52260	28.39438*	27.99141
2	-308.9520	52.43009*	9683387*	27.41267*	29.28968	27.67312*

Note: * indicates lag order selected by the criterion. LR: sequential modified LR test statistic (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion
Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author's calculation

Table 4: Optimal lag length selection.

as a factor of a more prolonged effect, excluding sharp or abnormal climate changes (e.g. extremely low wheat yield due to temperature spike in 2010, resulting in low rainfalls). Interestingly, Schwarz criterion captures these anomalies, serving as an argument for choosing 1 year as an optimal lag. However, we choose the lag, according to AIC and FPE.

Once we have determined that all variables are stationary at first difference we can present Johansen cointegration test for determining the appropriate type of regression model to use in the study. For Johansen test, we use non-stationary data to check for presence of relationship between sampled variables (Table 5).

Johansen test results show presence of cointegration between a number of equations, which allows presuming the existence of a long-term relationship between them. Trace Statistics for null hypothesis of no cointegrating equations between variables being larger than the critical value, and p-value being less than significance level of 5% give us right to reject the null hypothesis. In other words, we can assume existence of long run causality between variables.

Starting from the results of the cointegration test, we can proceed to the construction of VEC model to reveal presence or absence of long-term and short-term relations between variables.

The model shows the relationship between NPL and explanatory variables (sunspots, wheat yield, and world wheat prices). The results of the model estimation, showing the relationship between above-mentioned variables are presented in Table 6. Dependent variable is dynamics of non-performing bank loans for agricultural sector. Explanatory variables include sunspots, world wheat prices and wheat yield in Russia. To test for causality in the long term running from explanatory variables to dependent variable error correction term C1 must be negative in sign and statistically significant to reject the null hypothesis on no long run causality.

As can be seen from the Table, the value of error correction term C(1) is negative in sign and statistically significant. This suggests the existence of long-run causality between the variables of the sample. In other words, we can assume that NPL, sunspot cycles, wheat yield and world wheat prices have similar trends of movement in the long run on the one hand. On the other hand, we can assume that sunspots, world wheat prices and wheat yield in Russia cause changes in the share of the NPL in the long-run.

This result confirms the existence of a relationship between long-term trends of agricultural (wheat)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistics	0.05 Critical Value	Prob.**
None*	0.861247	84.24884	47.85613	0.0000*
At most 1	0.499327	21.82239	29.79707	0.1035
At most 2	0.363965	11.18259	15.49471	0.2005
At most 3	0.033137	0.775061	3.841466	0.3787

Note: * denotes statistical significance at the 5% level of significance

Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author’s calculation

Table 5: Results of Johansen co-integration test.

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-0.378891	0.096698	-3.918314	0.0018*
C(2)	0.003590	0.196963	0.018227	0.9857
C(3)	0.252026	0.197597	1.275452	0.2245
C(4)	-0.000981	0.008204	-0.119617	0.9066
C(5)	0.007553	0.008436	0.895265	0.3869
C(6)	-0.299510	0.092789	-3.227858	0.0066
C(7)	-0.246822	0.105264	-2.344797	0.0356
C(8)	-0.011227	0.007174	-1.564968	0.1416
C(9)	-0.004032	0.007287	-0.553355	0.5894
C(10)	-0.020823	0.203715	-0.102218	0.9201

Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author’s calculation

Table 6: Results of VECM estimation.

lending cycles and sunspot cycles. The error correction term C(1) is a long run equilibrium coefficient. The C (1) shows speed of long run adjustment. In other words, this coefficient shows how fast the system of interrelated variables would be restored back to equilibrium in the long run or the disequilibrium would be corrected. Given statistical significance at 5% level (p-value being less than 5%) and negative meaning, the system of variables corrects its previous period disequilibrium at a speed of 37,88% in two years (given optimal lag meaning of two years for ECM). It implies that the model identifies the sizeable speed of adjustment by 37,88% of disequilibrium correction in 2 years for reaching long run equilibrium steady state position.

The result of long-run causality between solar cycles, crop yield and wheat price is in line with existing studies on this issue (e.g. Monteith,1972; Garnett et al., 2006; Pustil'nik and Yom Din, 2013). However, the causal linkage with bad bank debts dynamics can be viewed as a new founding in our case.

On the other hand, of interest is the question about short-term sensitivity of agricultural lending cycles to changes in solar activity. In case of short-term crop yield' dependence on sunspots directly or indirectly, one can argue about importance and need to consider cosmic and climate changes when building models for crops yield forecasting and, consequently, assessing credit risk and evaluating amounts of financial support to agriculture. The rest of error correction terms represent the base for determining short-run causality coming from solar cycles (C4, C5), wheat yield (C6, C7) and world wheat prices (C8, C9).

To identify short-term causality between the variables we refer to the Wald test results. This test allows determining the interrelationship between variables in the short term. In other words, under the null hypothesis of this test, the response of error correction term to explanatory variables equals zero, i.e. sensitivity of resulting variable to changes (shocks) in explaining is not observed. Results of Wald Test for the model are presented in Table 7.

Based on the results of Wald Test one can detect significant short run causality coming from wheat yield to NPL with rate of adjustment towards equilibrium of 24,68% in t-2 and almost 30% in t-1. As can be seen from the results of the Wald test in the short run cycles of agricultural lending are sensitive to changes in wheat yields, that is the logical manifestation of the relationship between operating and financial production cycles. A decrease in yield leads to emergence of NPL and vice versa. In the short run, sensitivity of NPL to dynamics of sunspots has not been found, which suggests a more long-term and possibly indirect effect of solar radiation on the cycles of agricultural lending. However, one should be aware that the level of NPL cannot directly be determined only by bursts of solar activity. As we noted in the previous section, many factors explain the lack of short-term sensitivity. These include climatic and natural factors. The lack of short-term relationship between NPL and the world prices for wheat is due to the exporting status of Russia on the one hand, and on the other, the fact that most of the wheat is consumed on the domestic market, leading to insignificance of this factor in the short term. (AEGIC,2016)

In order to determine predictive causal relationships between variables in an attempt to detect significance of solar activity for wheat yield and, consequently, on dynamics of NPL in the market for wheat,

Test Statistic	Value	df	Probability
Null Hypothesis: C(4) = C(5) = 0 (Sunspots)			
F-statistic	0.4295	(2, 13)	0.6597
Chi-square	0.8590	2	0.6508
Null Hypothesis: C(6) = C(7) = 0 (Wheat Yield)			
F-statistic	6.6216	(2, 13)	0.0104*
Chi-square	13.2432	2	0.0013*
Null Hypothesis: C(8) = C(9) = 0 (World Wheat Prices)			
F-statistic	1.4604	(2, 13)	0.2678
Chi-square	2.9208	2	0.2678

Note: * denotes statistical significance and rejection of Ho: no short-run relationship
Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author's calculation

Table 7. Wald test results for short run relationship

we present results of the Granger causality test (Table 8).

As can be seen from Table 8, solar cycles and changes in wheat yield do Granger cause changes in NPL, given p-values being less than the significance level of 5%, so we can reject the null.

Given these results we can assume that solar activity, represented in Wolf numbers as well as wheat yield are useful in forecasting dynamics of non-performing banks loans for agricultural market in part of market for wheat. According to Granger, causality in economics can be tested by measuring ability or potential of predicting future values of time series by using prior values of another time series. That is Granger causality test presents predictive causality. In our case, results show that wheat yield and solar cycles can be used to predict future values of NPL and wheat yield.

Since we have already detected presence of long run causality between the variables by estimation of error correction model, identified short term causality running from wheat yield to NPL, results of Granger test give additional support to our hypothesis that sunspots actually do matter for cycles in agricultural lending by testing for predictive causality. In other words, solar cycles data can be used to forecast wheat yield, which determines in short run dynamics of non-performing loans for wheat market.

The final stage of the analysis of the constructed model is checking its quality. To do this, we refer to the series of diagnostic tests to validate the model on the absence of serial correlation, partial autocorrelation in the residuals, presence of homoscedasticity, normality and stability. The test results are presented in Table 9 and Figures 1-3.

Dependent variable: Non-performing agricultural loans (wheat production)	Chi-sq	df	Probability (P-value)
Sunspots	0.859071	2	0.6508
Wheat Yield	13.24328	2	0.0013*
World wheat prices	2.920888	2	0.2321
All	18.75226	6	0.0046
Dependent variable: Wheat Yield	Chi-sq	df	Prob.
NPL	3.425512	2	0.1804
Sunspots	7.265984	2	0.0264*
World wheat prices	0.480445	2	0.7865

Note: * denotes rejection of null hypothesis of no Granger causality
Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author's calculation

Table 8: Results of Granger causality test.

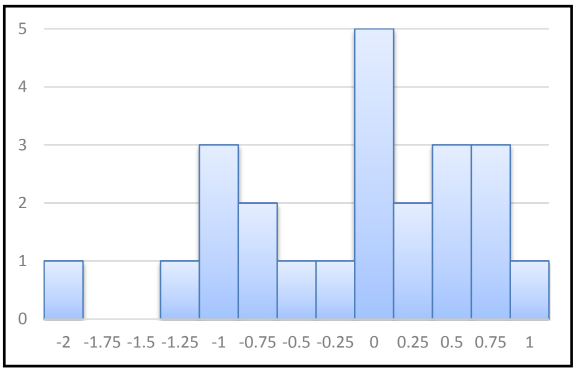
Auto, Partial auto correlation test results				
Lag number	AC	PAC	Q-Stat	Prob**
1	-0.239	-0.239	1,50	0.221**
2	0.030	-0.029	1,52	0.467**
Breusch-Godfrey Serial Correlation LM Test:				
F-statistic	1.123842	Prob. F(2,11)	0.3597**	
Obs*R-squared	3.902321	Prob. Chi-Square(2)	0.1421**	
Heteroskedasticity Test: Breusch-Pagan-Godfrey				
F-statistic	0.244052	Prob. F(12,10)	0.9879*	
Obs*R-squared	5.210014	Prob. Chi-Square(12)	0.9506*	
Scaled explained SS	1.354953	Prob. Chi-Square(12)	0.9999*	
Heteroskedasticity Test: ARCH				
F-statistic	0.003995	Prob. F(1,20)	0.9502*	
Obs*R-squared	0.004394	Prob. Chi-Square(1)	0.9472*	

Note: **denotes acceptance of null hypothesis (Ho: there is no auto/partial, serial correlation).
* denotes acceptance of null hypothesis of homoscedasticity.
Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author's calculation

Table 9: Results of diagnostic testing.

As can be seen from Table 9, the model meets the criteria of homoscedasticity of residuals and absence of serial correlation. As can be seen from Figure 1 and Table 10, the requirement of normality is also met. Testing the model for stability by means of CUSUM and CUSUM of Squares tests also confirms its stability.

These results allow us to assume that the results obtained are valid and of undistorted nature.



Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author's calculation

Figure 1: Results of normality test (1).

Mean	3.26e-17
Median	0.138762
Maximum	1.093412
Minimum	-1,766345
Std. Dev.	0.730946
Skewness	-0,583602
Kurtosis	2.628112
Jarque-Bera	1.438136
Probability	0.487206

Source: FAOSTAT, FEDHEMR, FSSR and Bank of Russia; author's calculation

Table 10: Results of normality test (2).

Conclusion

This study focuses on finding the relationship between sunspot cycles and cycles in agricultural lending in the context of wheat market on example of Russia. According to our hypothesis, a relationship between solar cycles, wheat yield, non-performing bank loans and wheat prices should exist in long and short run.

The main objective of this study was to find arguments to justify the need to consider climatic factors in lending practice of commercial banks. In case of incorrect assessment of potential yields, the result may be a suboptimal amount of funding or the size of loans, which will lead the loss of solvency (creditworthiness) of the borrower-farmer or even to default.

The results of the study show that for the long run causality between NPL, solar cycles, wheat yield and wheat prices does exist. Particularly, according to results of ECM estimation, the speed of adjustment towards equilibrium between sampled variables is 37,88% with two years lag. In the short-run, we've detected causality between bad debts' dynamics and wheat yield, stating that the rate of adjustment towards equilibrium between NPL and wheat yield is 24,68% in t-2 and almost 30% in t-1 periods. Also, the analysis of predictive causality, using Granger causality test, shows that wheat yield and solar cycles do Granger cause NPL. In this sense, we receive additional confirmation of solar cycles and wheat yield being tools for predicting crop yield.

However, the part of the hypothesis stating that there exist a short-run causality between world wheat prices and NPL has gained no support in case of Russian wheat market. We assume that this result is largely due to exporting status of Russia on this market.

In any case, the obtained results give a certain theoretical background for improving lending practices for Russian commercial banks when dealing with agricultural sector, especially wheat market.

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